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RAPID GEODETIC SURVEY SYSTEM (RGSS) WHITE SANDS TESTS FOR POSITION, HEIGHT, AND THE ANOMALOUS GRAVITY VECTOR COMPONENTS

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ABSTRACT

The following paper presents test results with the Rapid Geodetic Survey System (RGSS) used at White Sands Missile Range (WSMR), NM in 1980. Numerous traverses were surveyed with the inertial system carried in a truck and in a helicopter. The performance of the system in interpolating position, height, and the anomalous gravity vector components is statistically characterized.

INTRODUCTION

The RGSS is an inertial positioning system implementing modified platform control software to enhance the inertial system's capability to interpolate deflections of the vertical. Simultaneously, the system can provide position, height, and estimates of the free-air gravity anomaly. The greatest accuracy is obtained when missions are closed on a known station permitting the observation of an error in the quantity measured (ϕ-latitude, λ-longitude, H-height, ξ-meridian deflection component, η - prime vertical deflection component, Δg-free-air gravity anomaly). Following error smoothing or adjustment improved estimates are provided at intermediate points along the traverse.

A test area was developed at WSMR to accommodate the system while traversing in a ground vehicle and in a helicopter. The test area is composed of eleven traverses with three running approximately in a NE-SW direction, two oriented approximately in a N-S direction, five running generally in a E-W direction, and one oriented nearly NW-SE (see Figure 1). These courses are seen to cross each other at various points throughout an area approximately 30 by 32 km in dimension. The status of existing survey control for the test tract is as follows:

Known values for geodetic position and height are available at 60 interior stations on traverses through the area. Thirty of these stations exist at a junction point of at least two traverses.

Known values of the free-air gravity anomaly are available at 60 interior stations on traverses through the area. Thirty of these stations exist at a junction point of at least two traverses.

Known values for the meridian and prime vertical deflection components are available at 29 interior stations on traverses through the area. Twenty of these stations exist at a junction point of at least two traverses.

In addition to those listed above, 18 stations around the perimeter of the area have all geodetic values known and are used as initial and final fixed stations for traversing. Estimated standard

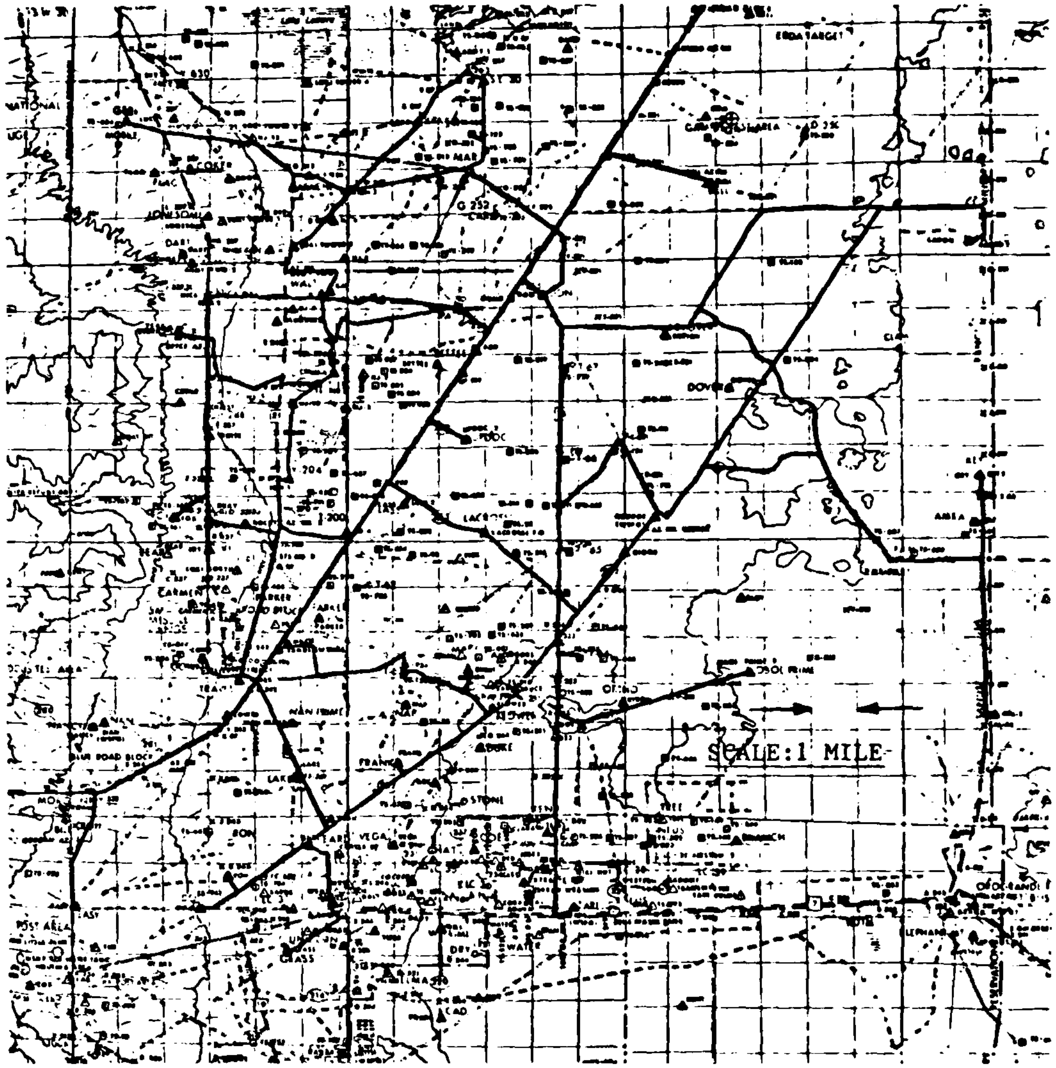

FIGURE 1

Test Tract and Traverses

East-West Traverses: Geri to Bell, Nick-2 to Largo-2, Bryce to Key-2, Fox-2 to Jar, Conn to Oboe Prime-2

Northeast-Southwest Traverses: Fry to SE-30, Easy to Otero, Dog to Largo-2

North-South Traverses: Grass to Nick-2, Tare to SE-30

Northwest-Southeast Traverse: Cal-2 to SE-30

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deviations associated with the known geodetic values are 0.08 meter for position relative to the local WSMR datum origin, 0.03 meter for height relative to local first-order bench marks, 0.25 arc-second for each deflection component in an absolute sense, and 0.1 milligal for the gravity anomaly in an absolute sense. Having introduced the system and test area, the next section discusses operational aspects.

TEST DESIGN AND PROCEDURES

The objective of these tests was to establish more definitely the capabilities of the RGSS in surveying for all geodetic values. The plan was to conduct the tests in two vehicle modes--on the ground in a land vehicle and in a helicopter to assess any differences in system performance and capability.

In each mode of operation, the 11 traverses in the test tract were surveyed twice-- one time from each end. This resulted in 22 ground vehicle missions and 22 helicopter missions over the same traverses. Prior to the survey missions in each mode careful calibration of the system was undertaken. Platform azimuth drift bias was calibrated and numerous dynamic calibration missions were completed to determine level accelerometer scale factors and sensitive axes misalignments for all three accelerometers.

The ground vehicle missions were conducted first followed by those in the helicopter. In each mode, the system was warmed (turned-on and put in fixed gain) for approximately 1-hour before commencing with the 1-hour premission alignment at the initial station of a traverse. For the ground vehicle phase, all premission alignments were 1-hour or full length in duration. Half of the helicopter missions were 25-minute alignments. Since platform azimuth drift bias was well compensated and helicopter missions were speedy, no disadvantage in positioning occurred in these missions. Another factor differentiating ground vehicle and helicopter missions was that in the helicopter mode the inertial measuring unit (IMU) was removed from the craft to the survey monument for every zero-velocity update (ZUPT). This was necessary since any attempt to perform a ZUPT in the helicopter induced severe vibration into the IMU disrupting the ZUPT process. The allowable 1^{σ} level of the velocity observations could have been increased to enable ZUPT-ing in the helicopter; but, resulting deflection change estimates would have then become adversly influenced by platform tilt errors caused by the excessive vibration and resulting noisey velocity observations. The operational technique of removing the IMU from the helicopter to the survey monument for ZUPTs, and hence marks, was a unique feature of these helicopter tests. This technique and the increased speed of mission execution in the helicopter mode are cited as paramount reasons for the improved performance in the flying mode. The IMU was not removed from the ground vehicle for ZUPTs; this is the usual operational procedure and no significant advantage would be expected with IMU removal.

A typical mission in either vehicle mode consisted of an alignment at the initial station of the traverse, surveying with about 3.5-minute travel periods through 10 stations (average) to the end station of the course, updating of position and height, on-line smoothing or adjustment of position and height, and hand-recording of the smoothed positional and height data. During the survey, hand-recording was on-going for the parameters estimating deflection and

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gravity anomaly change and the time at a particular station. While these data are all automatically recorded on cassette tape for later print-out, the recording effort was undertaken to insure against possible recording unit failures. This manual recording at stations extended each ZUPT on the average 25 seconds causing little increase in overall mission time. Smoothing of the deflections and gravity anomaly is completed off-line at a later time since these algorithms are not programmed in the system computer. For all these missions deterministic linear smoothing was done for each of the anomalous gravity vector components.

With a variety of missions available in each mode, evaluation of performance can be made in several different categories of interest. Therefore, the next section provides statistics characterizing performance with a single pass over a traverse, with a double pass (mean of forward-reverse) on a traverse, with the mean of a pair of single crossing passes at network junction points, with the overall mean of two forward-reverse schemes at junction points, and after a least-squares adjustment of all missions in each survey mode.

TEST RESULTS

With introductory and explanatory information in mind this section now presents the results of tests in each vehicle mode. Given a particular category of interest, for example, say the single pass scenario, ground vehicle statistics are given first followed by the helicopter results. For each of these categories, traverses ran in each mode were the same and all reduction computations were identical.

It is important to note that the following statistics are average values obtained by considering errors along a whole traverse or over an area. Therefore, the statistics indicate the average expected value anywhere along a traverse or over an area depending on the category considered.

The first category cosidered is performance on a single pass in any direction. All test tract single passes were evaluated so the statistics accurately characterize capabilities on any single pass for traverses as straight and long as these. Tables 1a and 1b present ground vehicle and helicopter results respectively.

Table 1a - Ground Vehicle Single Pass

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.00	0.12	-0.16	-0.6	0.5	-0.2
Average σ	0.45	0.38	0.18	1.4	1.1	2.1
Average RMS	0.45	0.40	0.24	1.5	1.2	2.1
Maximum Error	1.26	1.14	-0.87	-4.6	5.3	7.3
n-observations	198	198	196	116	116	199

Average Time/Distance until smoothing: 2.18 hours/34.8 km.

Table 1b - Helicopter Single Pass

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.04	0.09	0.13	0.2	0.1	-0.2
Average σ	0.28	0.23	0.23	0.8	0.7	2.0
Average RMS	0.28	0.25	0.27	0.8	0.8	2.0
Maximum Error	-1.16	1.03	1.31	2.1	-1.9	6.6
n-observations	220	220	219	120	120	210

Average Time/Distance until smoothing: 0.77 hours/29.6 km.

Note: Errors incurred after single passes over traverses and differencing smoothed values with known published values at stations.

In the tables above and in following presentations, statistics for geodetic values will be given with ϕ , λ , and H values in meters, ξ and η in arc-seconds, and Δg in milligals. The Average Error line gives the overall mean of the n-errors considered. This is a signed estimate of the bias. The Average σ line gives the average standard deviation of observed errors about the average error. This is a measure of precision or repeatability. The Average RMS line gives an estimate of the root-mean-square-error and is a measure of accuracy if the known published values are considered to be very accurate. The Maximum Error line shows what the largest deviation was between a smoothed geodetic value estimate and the known published value. The n-observations line indicates the number of observed errors evaluated to compute the statistics. If this number is large then one can be more confident about the numerical values given for the various statistical parameter estimates. The Average Time/Distance line indicates over all missions the elasped time required to run a mission (not including premission alignment) at which time the mission was closed and smoothing of all geodetic values performed. The Average Distance is the average traverse length. The Note following the latter table indicates the scenario of the survey in each mode and the derivation of observed errors.

Examination of Tables 1a and 1b shows much better performance in the helicopter mode except in the case of the gravity anomaly. Reasons cited earlier account for the superior helicopter mode performance; however, maximum errors are significant in both vehicle modes.

The next presentations, Tables 2a and 2b, give statistics for the mean of forward-reverse passes over the traverses--these are double pass statistics.

Table 2a - Ground Vehicle Double Pass

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.00	0.12	-0.15	-0.6	0.5	-0.2
Average σ	0.30	0.28	0.01	1.0	0.6	1.9
Average RMS	0.30	0.30	0.15	1.1	0.8	1.9
Maximum Error	-0.80	0.82	-0.45	-3.5	2.4	5.7
n-observations	94	94	93	58	58	96

Average Time/Distance until smoothing: 2.18 hours/34.8 km.

Table 2b - Helicopter Double Pass

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.04	0.09	0.14	0.2	0.1	-0.2
Average σ	0.15	0.20	0.17	0.5	0.6	1.6
Average RMS	0.16	0.22	0.22	0.5	0.6	1.6
Maximum Error	-0.48	0.97	0.67	-1.3	1.5	-4.2
n-observations	110	110	109	60	60	105

Average Time/Distance until smoothing: 0.77 hour/29.6 km.

Note: Errors incurred after performing forward-reverse passes over the traverses, computing the mean smooth values at stations, and differencing with the known published values.

A significant reduction in all statistics except average errors is seen in Tables 2a and 2b from Tables 1a and 1b. In general, a reduction factor from single pass level statistics of $1/\sqrt{K}$ can be expected. Here K is the number of independent missions providing an estimate of a geodetic value. The K estimates are averaged for an improved geodetic value estimate. It is emphasized that a second mission along a traverse in the same direction as some initial mission is not considered to be independent and will not result in significant error reduction. This claim is supported by results

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obtained on a Maryland test course in 1979. An overall 10 percent reduction in RMS from the single pass level was obtained with the mean of seven one-way missions used as a best estimate of geodetic values. Forward-reverse mean combinations yielded a 29 percent reduction in statistics. The approximate reduction factor in statistics from Tables 1 to Tables 2 in terms of RMS is $1/\sqrt{2}$, K = 2, for two independent passes.

Tables 3a and 3b next present similar results as seen in Tables 2. In this following category two single crossing passes are averaged at junction points around the network to provide best estimates. Only stations at the network junction points are evaluated for this category. Other stations intermediate to the traverse crossings are not included, these stations would have the singlepass level of statistics.

Table 3a - Ground Vehicle Two Single-Crossing Passes

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.06	0.15	-0.17	-0.5	0.4	-0.2
Average σ	0.32	0.31	0.12	1.1	0.8	1.4
Average RMS	0.33	0.35	0.21	1.2	0.9	1.5
Maximum Error	-0.95	1.03	-0.56	-3.5	3.4	-4.0
n-observations	242	242	242	184	184	256

Average Time/Distance until smoothing: 2.18 hours/34.8 km.

Table 3b - Helicopter Two Single-Crossing Passes

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.01	0.10	0.13	0.3	0.2	0.0
Average σ	0.23	0.19	0.15	0.6	0.5	1.4
Average RMS	0.23	0.22	0.20	0.7	0.6	1.4
Maximum Error	-1.03	0.75	0.75	2.0	1.4	4.3
n-observations	276	276	274	180	180	276

Average Time/Distance until smoothing: 0.77 hour/29.6 km.

Note: Errors incurred at network junction points after averages of two crossing single pass smoothed values are differenced with known published values at stations.

The above results present some ideas as to area densification methods. In order to achieve approximately a double pass level of accuracy quickly for an area it would be appropriate to run all traverses once in a single direction. A simple mean of smoothed estimates at network junction points would provide the above statistics at the junctions. Stations intermediate to crossings could be improved from single pass level statistics with non-linear smoothing and proper weighting employing the superior estimates at junction points. Junction points may be slightly degraded.

The next Tables, 4a and 4b, again consider statistics at network junction points. In this category <u>two</u> forward-reverse schemes are averaged at a junction to provide best estimates.

Table 4a - Ground Vehicle Two Double -Crossing Passes

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.07	0.15	-0.18	-0.5	0.5	-0.2
Average σ	0.21	0.22	0.03	0.7	0.6	1.2
Average RMS	0.22	0.27	0.18	0.9	0.8	1.2
Maximum Error	0.47	0.82	-0.36	-2.5	1.8	3.0
n-observations	55	55	55	46	46	63

Average Time/Distance until smoothing: 2.18 hours/34.8 km.

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Table 4b - Helicopter Two Double-Crossing Passes

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.01	0.10	0.13	0.3	0.2	0.0
Average σ	0.11	0.17	0.12	0.4	0.4	1.1
Average RMS	0.12	0.20	0.17	0.5	0.5	1.1
Maximum Error	-0.30	0.60	0.47	1.0	1.2	-2.6
n-observations	68	68	67	45	45	69

Average Time/Distance until smoothing: 0.77 hour/29.6 km.
Note: Errors incurred after forward-reverse mean values are averaged with crossing traverse's forward-reverse mean values at junction points and these values differenced with known published values at stations.

The above pattern of survey should be a minimum plan for area densification. The work required for this scheme is not excessive since each traverse need be run only twice, one time in each direction. The above statistics are obtained only at junction points, intermediate stations have the double pass level of accuracy. They could be upgraded in the same manner as discussed in the previous category. A reduction factor in statistics in terms of RMS between Tables 1 and 4 is approximately $1/\sqrt{4}$, K=4, for four passes at junction points.

The next category of statistics is given in Tables 5a and 5b which represent a quasi-optimal least-squares adjustment of all missions in each mode. This adjustment, performed at the Geodetic Survey Squadron, minimizes with the least-squares criteria the differences between forward and reverse smoothed geodetic values estimates while simultaneously minimizing differences at traverse crossing points. The least-square program employed in this adjustment also applies small variances to the perimeter fixed stations which are also treated as observations.

Table 5a - Ground Vehicle Least-Squares

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.01	0.16	-0.12	-0.5	0.3	-0.3
Average σ	0.13	0.15	0.12	0.5	0.6	1.3
Average RMS	0.13	0.22	0.17	0.7	0.7	1.4
Maximum Error	-0.37	0.55	-0.49	-1.7	1.3	-3.7
n-observations	61	61	60	29	29	60

Average Time/Distance until smoothing: 2.18 hours/34.8 km.

Table 5b - Helicopter Least-Squares

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	0.03	0.14	0.16	0.2	0.0	-0.5
Average σ	0.10	0.16	0.11	0.4	0.5	1.0
Average RMS	0.10	0.21	0.19	0.4	0.5	1.1
Maximum Error	0.31	0.63	0.48	-1.0	1.1	-2.6
n-observations	61	61	61	29	29	56

Average Time/Distance until smoothing: 0.77 hour/29.6 km.
Note: Errors incurred after least-squares geodetic value estimates from all missions in each mode are differenced with known published values at stations.

The desirability of a more optimal consideration of data is definitely clear from these results which show more consistency because all stations in the network are adjusted in the least-squares process and evaluated statistically. It is important to keep in mind that observations going into this adjustment were preprocessed by the on-line or off-line smoothing techniques. This is one reason why the adjustment is termed quasi-optimal. Much

better, and a required development, is an overall optimal adjustment model which employs raw system observations for each mission, uses the observed raw closing errors, and provides estimates of the required model error parameters, adjusted geodetic values, and covariance matrices.

Evident in all statistical presentations is the bias error in each geodetic value. With respect to position, the RGSS on-line smoothing algorithm accounts for level axes coupling affects; therefore, these average errors may be due to systematic residual accelerometer bias changes, quantizer rectification error with time, or uncompensated platform azimuth drift bias occurring over long duration missions, especially in the ground vehicle mode. The bias present in H is higher than expected and is likely due to level gyro drift coupling into the vertical axis not compensated in RGSS. The algorithm to effect this compensation has been developed by the manufacturer but not implemented thus far in on-line post-mission smoothing. For position and height, after 22 missions and the least-squares, little difference is seen between the two modes of survey. An optimal least-squares adjustment should reveal some superiority in the helicopter mode since mission closures are smaller. Uncompensated systematic level gyro drift, and additional tilt error due to integrated level gyro drift instability over long missions time-wise are not manageable by the off-line smoother for ξ and η therefore resulting in significant bias in the ground vehicle mode. Helicopter speed definitely helped reduce bias in ξ and η estimation. Gravity anomaly results are minimally improved in the helicopter mode.

Equally important for accuracy as time is a geometric parameter--it is the straightness of the inertial traverses. Consider the direct centerline between traverse end-points as line L with length L. Obviously, intermediate traverse stations converge toward the end-point stations and usually a maximum deviation between the intermediate stations and L occurs in the traverse interior. A geometric figure inclosing left or right deviating (from L) stations is a diamond. A symmetric diamond is constructed about L with the maximum deviation occurring at traverse mid-point. The deviation of this diamond on one side from L, expressed as a fraction of L, is the straightness parameter. The average maximum straightness parameter for these traverses was L/6.5 and 85 percent of stations along the traverses were inclosed. A factor influencing ground vehicle missions only was the road conditions for missions. Traverse routes were 35 percent paved, 30 percent gravel, and 35 percent field-road.

In conclusion of this section statistics are presented for special tests conducted in the ground vehicle. Since major heading changes are a significant factor in survey accuracy, two traverses with large heading changes were experimented on with the system. One traverse is V-shaped (L/0.9) with segments 15 and 21 km in length. The other course is L-shaped (L/2.3) with legs 19 and 20 km long. The IMU, usually hard-mounted in the ground vehicle, was put onto a turn-table inside the vehicle. With this facility, it is possible to manually orient the IMU case; and, to do this such that the relationship between the stable element (platform) and the IMU case is approximately constant. This means that sensitive inertial components (gyroscopes and accelerometers) remain in a steadier environment throughout a mission thereby reducing heading change induced drift rate and bias changes. To understand this

experimental arrangement be aware that the RGSS is a local-level north-pointing inertial system. Therefore, in operation the platform is always oriented east, north, and vertical with respect to accelerometer sensitive axes. The IMU case on the other hand, which incloses the gimbaled stable element, is normally attached to the vehicle and changes direction as the vehicle does throughout a mission -- the IMU case turns around the stable element, thus the changing environment about the sensitive inertial instruments. These experiments were conducted in an attempt to detect the magnitude of this problem.

The V-Shaped course was run four times with the IMU hard-mounted, as usual, and four additional passes were made with the IMU turned. The L-shaped course was run two times with the IMU turned. Tables 6a and 6b pertain to the V-shaped course and single passes with the IMU hard-mounted and turned respectively. Positioning is not accurate in the IMU-turned mode since the azimuth of the vehicles reference door marker is incorrect. Therefore, only H, ξ, η, and g-statistics are given for this mode.

Table 6a - Ground Vehicle, IMU Hard-Mounted, Single Passes

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	-0.25	-1.64	-0.08	0.5	-0.2	-0.3
Average σ	1.15	2.13	0.33	1.6	1.4	1.9
Average RMS	1.17	2.69	0.34	1.7	1.5	1.9
Maximum Error	-3.51	-6.86	-0.91	3.1	-3.5	-4.0
n-observations	60	60	64	48	48	46

Average Time/Distance until smoothing: 2.36 hours/36 km.

Table 6b - Ground Vehicle, IMU Turned, Single Passes

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	N/A	N/A	0.05	0.3	-0.4	0.3
Average σ	"	"	0.31	1.0	1.0	1.0
Average RMS	"	"	0.31	1.0	1.1	1.1
Maximum Error	"	"	1.35	2.4	-3.3	2.1
n-observations	"	"	56	47	47	43

Average Time/Distance until smoothing: 2.36 hours/36km.
Note: Errors incurred after four single passes over V-shaped traverse and differencing smoothed values with known published values at stations.

From Table 6a to 6b, in terms of RMS, 9 percent, 34 percent, and 42 percent improvements are noted in height, deflections, and the gravity anomaly respectively.

Next, Tables 7a and 7b give mean or double pass (mean of forward-reverse) statistics on the V-shaped course.

Table 7a - Ground Vehicle, IMU Hard-Mounted, Double Pass

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	-0.25	-1.69	-0.08	0.5	-0.2	-0.4
Average σ	0.86	1.69	0.28	0.8	0.7	1.1
Average RMS	0.90	2.39	0.29	1.0	0.7	1.1
Maximum Error	-1.79	-5.38	-0.56	2.2	-2.0	-3.1
n-observations	30	30	32	24	24	23

Average Time/Distance until smoothing: 2.36 hours/36 km.

Table 7b - Ground Vehicle, IMU Turned, Double Pass

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	N/A	N/A	0.05	0.3	-0.4	0.3
Average σ	"	"	0.22	0.5	0.7	0.9
Average RMS	"	"	0.22	0.6	0.8	1.0
Maximum Error	"	"	0.63	1.1	-1.9	-1.6
n-observations	"	"	27	23	23	21

Average Time/Distance until smoothing: 2.36 hours/36 km.
Note: Errors incurred after performing forward-reverse passes over V-shaped traverse, computing the mean smoothed values, and differencing with known published values at stations.

Minimal difference in terms of RMS is seen between Tables 7a and 7b.

Tables 8a and 8b next have statistics for IMU-turned missions on the L-shaped course. Table 8a is for two single passes and Table 8b presents statistics for a double pass (forward-reverse mean).

Table 8a - Ground Vehicle, IMU-Turned, Single Passes

	ϕ(m)	λ(m)	H(m)	ξ(sec)	η(sec)	Δg(mgal)
Average Error	N/A	N/A	-0.29	0.2	0.6	0.5
Average σ	"	"	0.44	0.8	0.6	0.8
Average RMS	"	"	0.53	0.9	0.9	0.9
Maximum Error	"	"	-1.53	-1.6	1.6	2.1
n-observations	"	"	28	26	26	26

Average Time/Distance until smoothing: 1.90 hours/39 km.

Table 8b - Ground Vehicle, IMU-Turned, Double Pass

Average Error	N/A	N/A	-0.30	0.2	0.6	0.5
Average σ	"	"	0.25	0.5	0.4	0.6
Average RMS	"	"	0.39	0.5	0.8	0.8
Maximum Error	"	"	-0.94	0.8	1.3	1.5
n-observations	"	"	14	13	13	13

Average Time/Distance until smoothing: 1.90 hours/39 km.
Note: Errors incurred (8a) after two single passes over L-shaped traverse and differencing smoothed values with known published values at stations; in 8b mean (from forward-reverse passes) values differenced with known published values at stations.

The L-shaped traverse results support those seen on the V-shaped course for ξ , η , and Δg- interpolation with the IMU turned. These results are also encouraging in that they indicate a technique in the interim for interpolating deflections and the gravity anomaly on courses with major heading change up to 2.36 hours in duration. The method is to mount the IMU on a turn-table in the ground vehicle and survey the course from each end on independent alignments taking the simple mean of the forward-reverse passes as the best estimates of deflection and anomaly values. According to these experiments, deflections with an average RMS value of 0.7 arc-second may be expected. Simultaneously, gravity anomalies at an average RMS value of 0.9 millgal can be anticipated. Height can also be somewhat improved over the standard operational technique.

On the V-shaped traverse almost as good a performance was seen with a double pass hard-mounted IMU as with the IMU turned. The reduction in deflection RMS was almost 50 percent from Table 6a to 7a. Normally this cannot be depended on to occur. Important statistics are those representing a single pass; from these results one can predict the performance expected with additional independent passes.

CONCLUSION

In the following, statistics were given portraying RGSS performance in a ground vehicle, helicopter, and with the IMU on a turn-table in the ground vehicle. Several different statistical categories were presented thereby indicating work scenarios with the system and corresponding capabilities. It has been emphasized that elasped time for a mission and the straigtness of the traverses are of primary importance in determining accuracy--shorter (time-wise) and straighter missions are always better. These statistics apply to these time length and type traverses.

In terms of RMS the helicopter mode compares to the ground vehicle mode over all categories covering identical traverses for each geodetic value as follows: 37 percent better in latitude, 26 percent better in longitude, 12 percent worse in height, 46 percent better in the meridian deflection component, 32 percent better in the prime vertical deflection component, and 11 percent better in the gravity anomaly. As shown by the time differences for different mode missions the helicopter is much faster. Accuracy requirements and time deadlines encountered in many survey projects may exceed increased cost and logistical considerations and favor the helicopter over the ground vehicle mode for surveys where both options are possible.

In the future better systems can be expected. Studies are on-going to assess current deficiencies in systems hardware and software and modifications will be recommended.

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